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Research Paper
PNW-344
October 1985

# Growth Response of Suppressed True Fir and Mountain Hemlock After Release



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## Abstract

**Seidel, K. W.** Growth response of suppressed true fir and mountain hemlock after release. Res. Pap. PNW-344. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 22 p.

The diameter and height growth of advance reproduction of suppressed true fir (*Abies* spp.) and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) was measured in south-central Oregon after release by overstory removal in clearcuttings, shelterwood units, and uncut stands. Postrelease growth was greatest in clearcuttings, intermediate in shelterwood cuttings, and slowest in uncut stands. Multiple regression analyses were used to predict growth response as a function of tree and stand variables. Overstory basal area, live crown ratio, and past 5-year height growth accounted for the most variation in diameter and height growth after release. Vigorous advance reproduction having live crown ratios greater than 50 percent are the best candidates for crop trees.

Keywords: Growth response, release, suppression (tree), advance growth, true fir, mountain hemlock.

## Summary

In 1983 and 1984, a study was conducted in the Cascade Range in south-central Oregon to obtain information about the diameter and height growth response of suppressed advance reproduction of grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), Shasta red fir (*Abies magnifica* var. *shastensis* Lemm.), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) after release by removal of the overstory. The purpose was to compare rates of diameter and height growth before and after release, to determine when increased growth occurs, and to develop models to predict diameter and height growth after release as a function of tree and stand variables, such as live crown ratio and basal area.

The study areas were clearcut and shelterwood units and uncut stands in upper slope, mixed conifer/snowbrush-chinkapin and mountain hemlock/grouse huckleberry communities in the Deschutes and Winema National Forests, south-central Oregon. Growth patterns 5 years before and 10 to 20 years after release of the trees were determined by sectioning trees.

Both diameter and height growth increased after release from two to four times the prerelease rate for both fir and hemlock. Acceleration of growth generally occurred within 5 years after release with the most rapid growth occurring on clearcut units. Growth curves had a sigmoid form showing constant growth before release, a rapid acceleration during the first 8 to 9 years after release, followed by a flattening of the curves from 10 to 20 years after release.

Residual overstory basal area, live crown ratio, and past 5-year height growth were the three variables accounting for most of the variation in diameter and height growth after release. Growth of the advance reproduction after release was directly proportional to live crown ratio or past height growth and inversely proportional to overstory stand density. Both fir and hemlock responded to release regardless of age.

The best potential crop trees are vigorous advance reproduction having live crown ratios greater than 50 percent and those with the greatest height growth before release. Releasing these trees by removing the overstory and by thinning when needed will not only greatly increase growth rates but will afford some protection against heartrots.

## Contents

## Introduction

A suppressed understory consisting of shade-tolerant species such as true firs (*Abies* spp.) and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) is present in many mixed conifer communities on the east slopes of the Cascade Range in central Oregon. Using this advance reproduction for the new stand after removing the existing overstory, instead of relying on natural or artificial regeneration, has advantages in many situations. One of the key factors in evaluating the potential of suppressed advance reproduction is the growth response of the trees after release. Of interest are whether trees will respond with increased diameter and height growth and, if so, the magnitude and timing of the response.

Many studies show that understories of true fir and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) will respond to release even though suppressed for many years (Crossley 1976, Ferguson and Adams 1979, Gordon 1973, McCaughey and Schmidt 1982, Seidel 1983). More information is needed, however, regarding the growth rates that can be expected and how soon a response will occur in various plant communities and for species other than fir or spruce. Of particular interest is mountain hemlock because of the lack of growth data for this species and the increasing interest in its management.

The purpose of this study was to obtain data on diameter and height growth response of advance reproduction of suppressed true fir and mountain hemlock after overstory removal in several mixed conifer communities on the east slope of the Cascade Range. Specific study objectives were: (1) to determine and compare rates of diameter and height growth before and after release for each species, (2) to determine how soon after release the increased growth response occurs, and (3) to screen specific variables to use in models for predicting diameter and height growth. This study expands on an earlier study that was limited to one species and a single stand (Seidel 1980b).

## Study Area

Study areas were clearcut and shelterwood units and adjacent uncut stands located in midslope to upperslope mixed conifer forests in the Deschutes National Forest in Deschutes County and Winema National Forest in Klamath County (fig. 1). Two plant communities are present on the study areas (Volland 1982): (1) a mountain hemlock/grouse huckleberry community and (2) a mixed conifer/snowbrush-chinkapin community. Elevations ranged from 1524 to 1950 meters (5,000 to 6,400 ft) and slopes ranged from 0 to 25 percent on all aspects.

Study areas were within the pumice plateau region of south-central Oregon. Soils in this region are immature Regosols (Vitrandepts) developed from aerially deposited dacite and rhyolitic pumice ejected from Mount Mazama (Crater Lake) about 6,500 years ago. These well-drained, coarse-textured soils have thin infertile A-horizons that grade into unweathered sand and gravel. A finer textured buried soil is found at a depth of 0.6 to 1.8 meters ( 2 to 6 ft) (Larsen 1976).

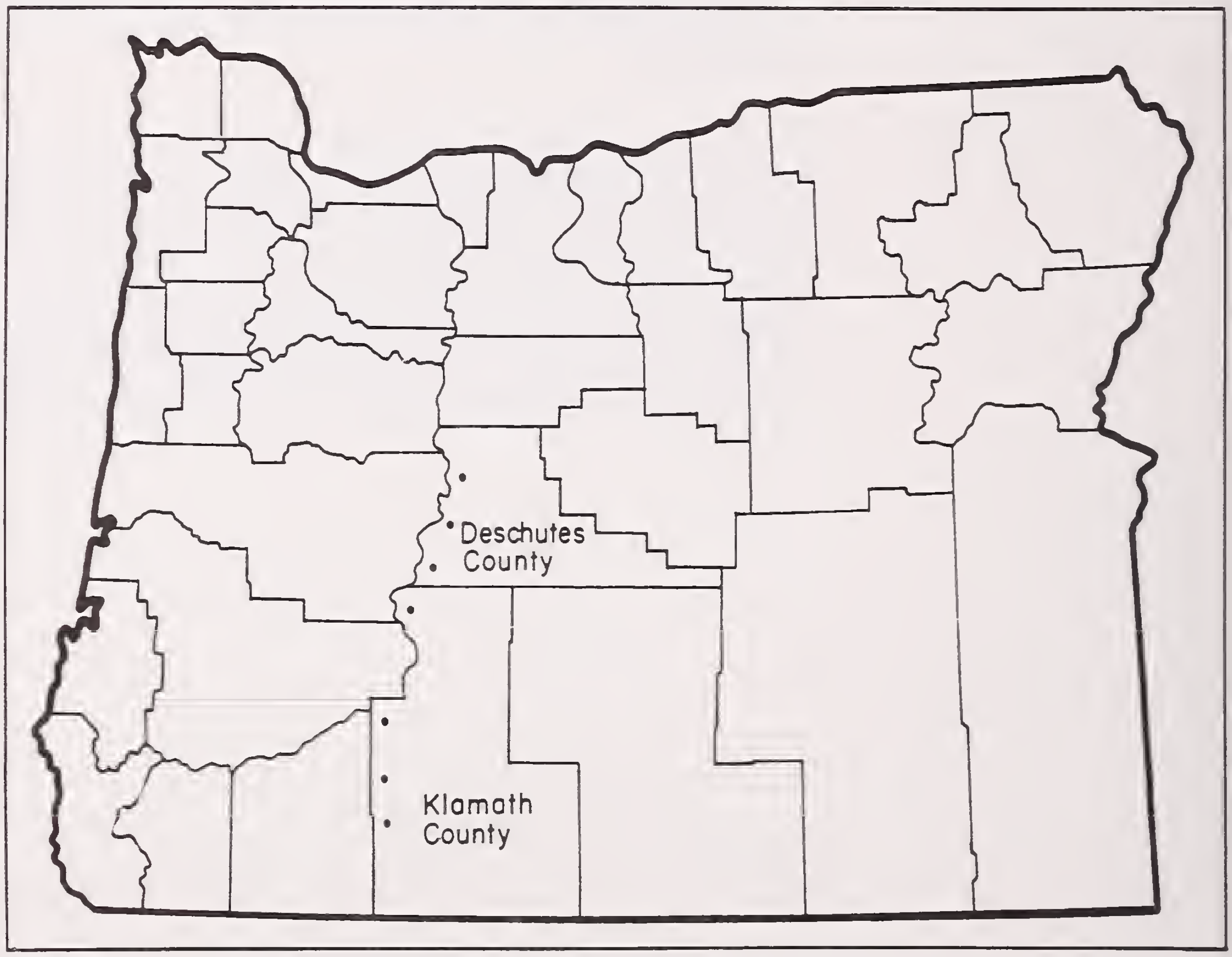


Figure 1.—Counties where study areas are located in south-central Oregon; three stands were sampled in the vicinity of each dot.

**Table 1—Mean and range of some characteristics of true fir and mountain hemlock advance reproduction in uncut, shelterwood, and clearcut units, Cascade Range, south-central Oregon, in 1983**

| | Uncut | | | | Shelterwood | | | | Clearcut | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | True fir | | Mountain hemlock | | True fir | | Mountain hemlock | | True fir | | Mountain hemlock | |
| Characteristic | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range |
| Diameter (d.b.h.) (centimeters) | 3.4 | 0.5-12.3 | 3.8 | 0.5-14.7 | 3.6 | 0.5-8.1 | 4.1 | 1.3-8.4 | 5.4 | 0.5-11.7 | 5.2 | 1.0-10.5 |
| Total height (meters) | 2.38 | .76-5.64 | 2.74 | .76-5.64 | 2.29 | 1.07-4.11 | 2.68 | 1.06-4.42 | 2.77 | .76-5.94 | 3.54 | 1.98-5.33 |
| Live crown ratio (percent) | 65 | 8-95 | 71 | 50-94 | 62 | 31-97 | 73 | 45-96 | 77 | 34-100 | 89 | 61-100 |
| Total age (years) | 92 | 21-260 | 104 | 56-250 | 79 | 26-179 | 100 | 45-196 | 67 | 16-171 | 73 | 27-134 |
| Years to reach breast height of 137 centimeters | 76 | 10-217 | 57 | 17-129 | 55 | 21-124 | 60 | 11-123 | 54 | 12-149 | 56 | 17-111 |

Species composition of the old-growth mixed conifer community consisted of about 52 percent grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), 23 percent Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), 17 percent Shasta red fir (*Abies magnifica* var. *shastensis* Lemm.), 5 percent ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) plus a few lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), western white pine (*Pinus monticola* Dougl. ex D. Don), and Engelmann spruce. In the mountain hemlock community, 51 percent of the overstory was mountain hemlock, 35 percent red fir, 6 percent grand fir, 5 percent white pine, and small numbers of spruce, lodgepole pine, and Douglas-fir. These stands were over 300 years old and averaged about 36 square meters per hectare of basal area (157 $ft^2$/acre) in the mountain hemlock type and 24 square meters per hectare (105 $ft^2$/acre) in the mixed conifer community.

Some characteristics of the suppressed understory trees derived from stem analysis are given in table 1. Height of the firs (grand fir and red fir) ranged from 0.8 to 5.9 meters (2.6 to 19.4 ft) and the mountain hemlock sampled were from 0.8 to 5.6 meters (2.6 to 18.4 ft) tall. Total age of sample trees ranged from 21 to 260 years for fir and from 27 to 250 years for mountain hemlock.

## Methods

Eight clearcuttings, six shelterwoods, and nine uncut areas were sampled in this study. The units were selected from among a larger number of units used in an earlier study that described the status of regeneration in mixed conifer communities in the Cascade Range in Oregon. The sampling design and criteria for selecting these units are given in earlier reports (Seidel 1979a, 1979b).

In 1983, a grid of 12 sample points spaced 50 meters (165 ft) apart was centrally located on each of the clearcut, shelterwood, and uncut units suitable for this study. To qualify as study areas, harvesting on cutting units must have occurred at least 10 years prior and have left at least 790 trees per hectare (320 per acre) of advance reproduction after logging. At each sample point, the true fir and mountain hemlock closest to the point were selected for sampling, subject to the following qualifications: (1) the tree had to be less than 6 meters (20 ft) tall, and (2) the tree had to be free of damage from logging and from dwarf mistletoe (*Arceuthobium* spp.). Because both a true fir and mountain hemlock were not found at every sample point, this procedure resulted in a total of 322 sample trees: 201 firs and 121 hemlock. Trees (both species combined) were distributed on cutting units as follows: clearcut—101; shelterwood—74; and uncut—147.

Trees selected for sampling were cut at ground level and the following measurements taken in the field:

1. D.b.h. (diameter at breast height).

2. Total height.

3. Live crown length. (The base of the live crown was defined as the point where at least two branches of a whorl were present. Single isolated branches below the main crown were not included.)

The overstory density (basal area) was measured at the location of each tree using a 10-factor basal area gauge. Aspect, slope percentage, and elevation were also recorded for each tree.[1/]

Sample trees were then brought into the laboratory and stem analysis was used to determine the size and age of the tree at the time of release (initial values) and the annual diameter and height growth for a 5-year period before release (preharvest) and a 5-, 10-, 15-, or 20-year period after release (postharvest).

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[1/] Aspect was coded by the method proposed by Day and Monk (1974) in which the following values were assigned to compass directions: N-14; NE-15; E-11; SE-7; S-3; SW-2; W-6; NW-10.

Diameter and height growth models were developed for individual true fir and mountain hemlock using stepwise regression procedures to fit to the data linear equations of the form:

$$Y = b_o + b_1X_1 + b_2X_2 + \ldots . b_nX_n \quad .$$

Dependent (Y) variables were:
- Postharvest, 5-, 10-, 15-, and 20-year diameter growth (millimeters) at ground level
- Postharvest, 5-, 10-, 15-, and 20-year height growth (centimeters)

Independent (X) variables were:
- Preharvest, 5-year diameter growth (millimeters) at ground level
- Preharvest, 5-year height growth (centimeters)
- Postharvest basal area (square meters per hectare)
- Initial diameter (millimeters) at ground level
- Initial height (centimeters)
- Initial crown length (centimeters) determined from aging branches at the base of the crown
- Initial live crown ratio (crown length/total height)
- Initial age (years)
- Aspect (code)
- Slope (percent)
- Elevation (meters)

Regression analysis assumes each tree to be independent and randomly selected from the whole study area. The individual trees used in this study were not completely independent because many trees were selected from each unit. Trees on a single unit are likely to be more similar than trees selected at random from the entire population and, if they are, the residual error about regression will be underestimated.

The sample size for these growth equations varied because not all cutting units had the same number of years of postharvest growth. All units were at least 10 years old, some were 15, and some 20.

Curvilinear equations of the form:

$$Y = a + b\,(1\text{-}e^{-cX})^d \quad ;$$

were used to relate average annual diameter and height growth (yearly means) to number of years before and after release for firs and mountain hemlock on clearcut and shelterwood units. After conversion to linear form, these curves were tested for significant differences in slope (b) and level (a) using methods described by Freese (1967). Growth measurements from year to year were not independent; therefore, the residual error about regression may be underestimated.

In 1984, an additional 44 firs and 34 hemlock were collected from the same study areas used in 1983 to provide an independent data set for testing the multiple linear regression growth models developed from the 1983 data. Comparisons of the actual versus the estimated growth on the 1984 data set showed that both diameter and height growth were consistently underestimated from 7 to 93 percent by the models. After this comparison was made, data from both 1983 and 1984 were combined and new regression equations were fitted to the pooled data resulting in a total sample of 400 trees: 245 fir and 155 hemlock.

## Results

### Diameter Growth Showed Marked Response

Diameter growth of both the firs and mountain hemlock showed a marked response to release compared to the preharvest growth rate. In both clearcut and shelterwood units, the true firs grew faster than hemlock after release; in the uncut stands growth rates were about equal for both species during all five growth periods (fig. 2). As expected, the greatest diameter growth occurred in the clearcuttings, somewhat less in the shelterwood units, and the uncut units showed little change over time. Average growth of hemlock in shelterwood units during the first 5-year period after release was 1.5 times the preharvest growth rate and increased to 2.3 times the preharvest rate during the second 5-year period. Growth of firs in shelterwoods was 1.8 times faster during the first 5-year period compared to the preharvest rate and accelerated to 3.7 times the preharvest rate during the second period.

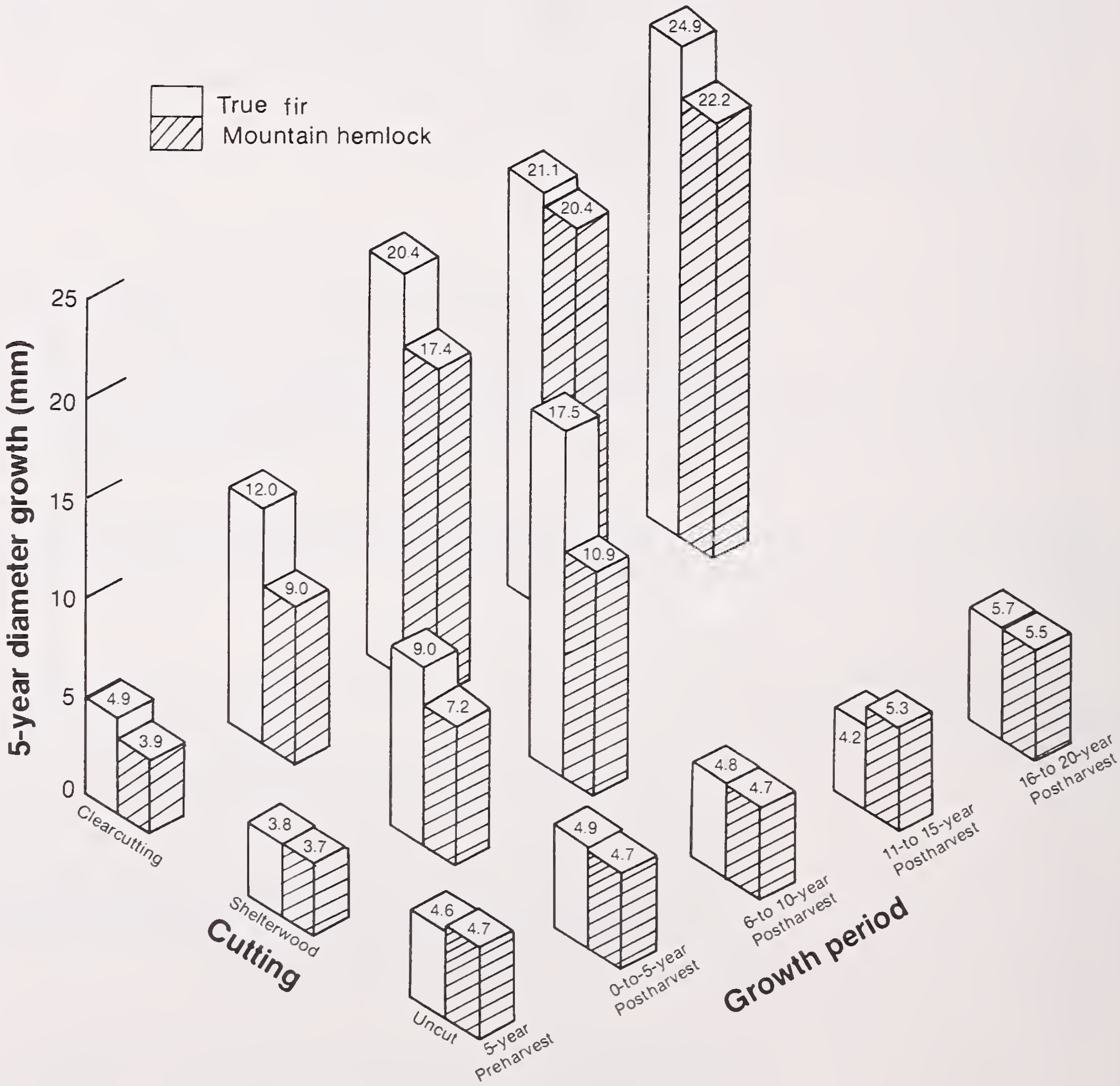


Figure 2.—Periodic diameter growth of true fir and mountain hemlock by cutting method and by preharvest or postharvest 5-year growth period.

In clearcut units, the greater response after release resulted in a growth rate for fir during the first period that was 2.5 times the preharvest rate and reached a maximum of 5.0 times the preharvest rate during the third period. Hemlock responded in a similar, but slightly slower, manner with growth increasing from 1.9 to 4.3 times the preharvest rate from the first to third period after release. The maximum average diameter growth rate of 25 millimeters (1 in) in 5 years occurred on firs in clearcuttings during the fourth growth period (16 to 20 years after release).

In shelterwood units, average annual diameter growth rates of both fir and hemlock were the same before release (fig. 3). After release, the curves diverged, the firs showing a more rapid growth rate and a continuing upward trend after 10 years compared to slower growth of the hemlock and a leveling off of the curve. These curves are significantly different ($P < 0.01$) in both slope and level. Growth rates for both fir and hemlock the second year after release were slightly greater than the prerelease rates but it was not until the third to fourth year after release that a more rapid acceleration in the growth rate occurred. The general pattern of diameter growth after release in the shelterwood units appeared, however, to be a gradual rather than an abrupt increase in growth over time.

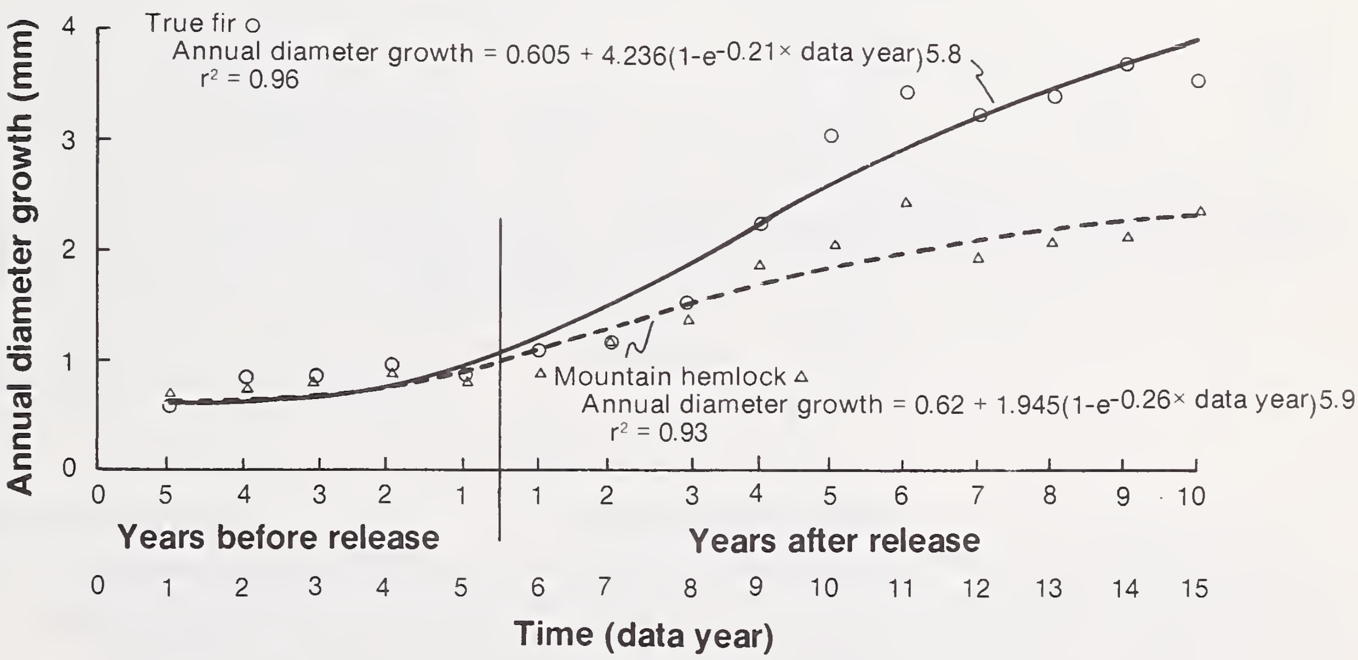


Figure 3.—Annual diameter growth, as a function of time, of true fir and mountain hemlock on shelterwood units. Relationship shows average growth response before and after release for all trees. Mean values for each year were used to calculate equations.

For clearcut units, both fir and hemlock diameter growth curves exhibited the classical sigmoid form showing relatively constant growth before release, a rapid acceleration of growth during the first 8 to 9 years after release, followed by a flattening out of the curves from 10 to 20 years after release (fig. 4). No significant difference in either slope or level was found between these curves. In contrast to the more gradual increase in diameter growth after release found in shelterwood units, diameter growth of both fir and hemlock in these clearcut units showed an immediate response to release. Growth the first year after release was about 1.8 times the 5-year prerelease average growth rate.

The sigmoid form of these growth curves showed that the initial rapid acceleration of diameter growth after release is not maintained. This is clearly seen for clearcut units where growth rates are constant 15 to 20 years after release (fig. 4). Although only 10 years of data after release are available for shelterwoods (fig. 3), the hemlock curves appear to be leveling off and the fir curve, although still rising, will probably begin to level off within the next 10 years.

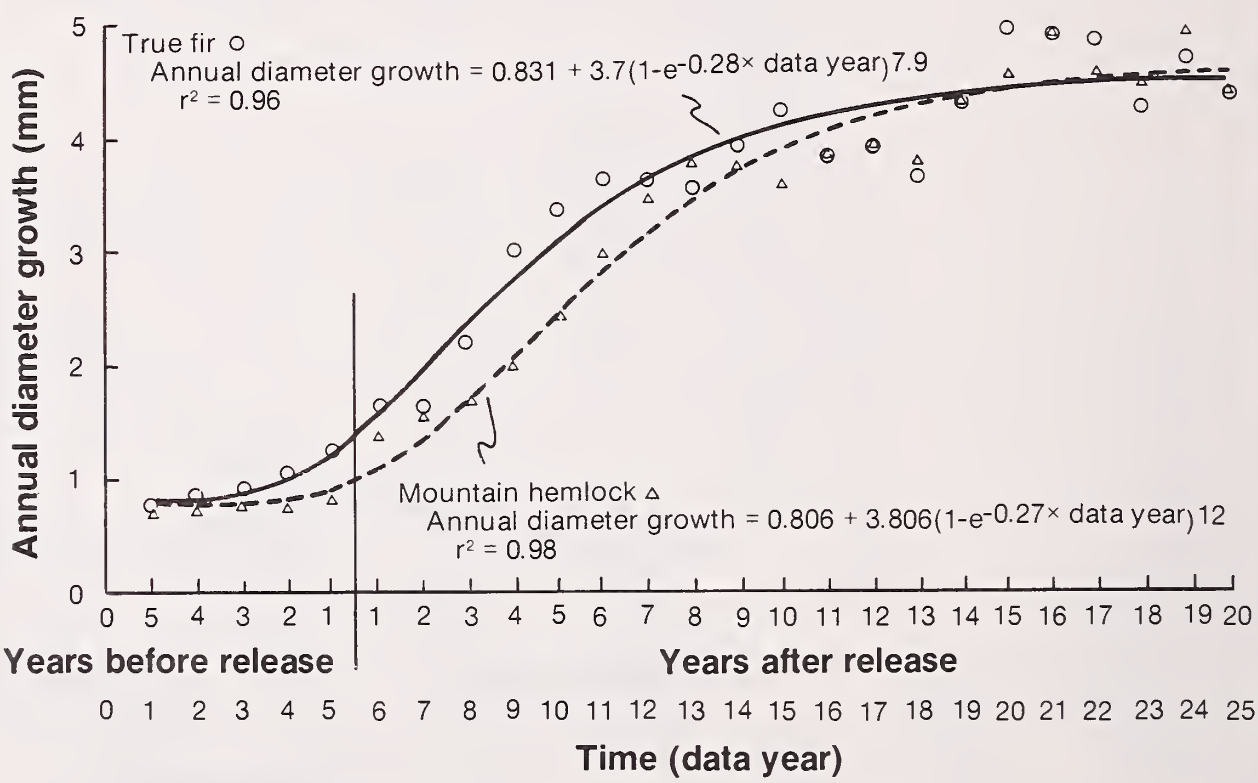


Figure 4.—Annual diameter growth, as a function of time, of true fir and mountain hemlock on clearcut units. Relationship shows average growth response before and after release for all trees. Mean values for each year were used to calculate equations.

**Table 2—Relationship of independent variables to 5-year, 10-year, 15-year, and 20-year diameter growth of suppressed understory of true fir saplings**

| Independent variables 1/ | Equation | Percent of variation explained ($R^2$) 2/ | Standard error of estimate (Sy·x) |
|---|---|---|---|
| | 5-YEAR DIAMETER GROWTH | | mm |
| LCR | 3/ y = 0.9573 + 0.1671 (LCR) | 0.25 | 6.1 |
| LCR, BA | y = 6.012 + 0.1191 (LCR) - 0.1587 (BA) | .36 | 5.7 |
| LCR, BA, HG5 | y = 3.330 + 0.1102 (LCR) - 0.1491 (BA) + 0.1368 (HG5) | .43 | 5.4 |
| LCR, BA, HG5, A | y = 0.3495 + 0.1102 (LCR) - 0.1610 (BA) + 0.1521 (HG5) + 0.3071 (A) | .47 | 5.2 |
| | 10-YEAR DIAMETER GROWTH | | |
| BA | y = 32.972 - 0.6173 (BA) | .28 | 15.7 |
| BA, LCR | y = 15.431 - 0.4493 (BA) + 0.3095 (LCR) | .39 | 14.5 |
| BA, LCR, A | y = 9.850 - 0.4763 (BA) + 0.3115 (LCR) + 0.6394 (A) | .42 | 14.2 |
| BA, LCR, A, HG5 | y = 3.610 - 0.4613 (BA) + 0.2940 (LCR) + 0.7384 (A) + 0.1742 (HG5) | .45 | 13.7 |
| | 15-YEAR DIAMETER GROWTH | | |
| BA | y = 50.777 - 1.1125 (BA) | .44 | 20.8 |
| BA, LCR | y = 26.081 - 0.8340 (BA) + 0.4214 (LCR) | .54 | 19.0 |
| BA, LCR, HG5 | y = 15.254 - 0.7835 (BA) + 0.4008 (LCR) + 0.5793 (HG5) | .58 | 18.1 |
| BA, LCR, HG5, A | y = 8.770 - 0.3512 (BA) + 0.4187 (LCR) + 0.5251 (HG5) + 0.9377 (A) | .61 | 17.5 |
| BA, LCR, HG5, A, DG5 | y = 7.982 - 0.7978 (BA) + 0.4667 (LCR) + 0.6331 (HG5) + 1.0723 (A) - 1.2841 (DG5) | .64 | 17.1 |
| | 20-YEAR DIAMETER GROWTH | | |
| BA | y = 70.796 - 1.4134 (BA) | .50 | 25.3 |
| BA, LCR | y = 42.367 - 1.1942 (BA) + 0.4892 (LCR) | .57 | 23.5 |
| BA, LCR, A | y = 36.479 - 1.2733 (BA) + 0.4251 (LCR) + 1.5923 (A) | .62 | 22.3 |
| BA, LCR, A, DG5 | y = 37.772 - 1.2195 (BA) + 0.4912 (LCR) + 1.7098 (A) - 1.5382 (DG5) | .65 | 21.6 |

1/ LCR = live crown ratio (percent); BA = postharvest overstory basal area (in square meters per hectare); HG5 = height growth 5 years before release (in centimeters); A = aspect (code); DG5 = diameter growth 5 years before release (in millimeter). Variables are arranged in the order in which they entered the regressions. Only variables that accounted for major portions of the variation in growth are given. Variables were excluded if they failed to raise $R^2$ values by at least 2 percent.

2/ All are significant at the 1-percent level.

3/ y = diameter growth in millimeters.

The models predicting 5-, 10-, 15-, and 20-year diameter growth for true firs are given in table 2. For all growth periods, except the 5-year period, the best single variable equation involved basal area of the residual overstory and explained from 28 to 50 percent of the variation in diameter growth. Live crown ratio was the next variable to enter the equations and increased $R^2$ values about 10 percent. Similar diameter growth models for mountain hemlock are given in table 3. In these models, basal area, and past diameter or height growth accounted for the major portion of the variation in diameter growth.

Estimates of fir and hemlock diameter growth for 10- and 20-year periods after overstory removal, as a function of postharvest basal area and live crown ratio, are given in appendix tables 6 and 7. These models are less sensitive than the more complete models given in tables 2 and 3 but both basal area and live crown ratio account for a considerable amount of total variation and can easily be measured in the field.

**Table 3—Relationship of independent variables to 5-year, 10-year, 15-year, and 20-year diameter growth of suppressed understory of mountain hemlock saplings**

| Independent variables 1/ | Equation | Percent of variation explained ($R^2$) 2/ | Standard error of estimate (Sy·x) |
|---|---|---|---|
| | 5-YEAR DIAMETER GROWTH | | mm |
| DG5 | 3/ y = 3.351 + 1.0882 (DG5) | 0.15 | 6.4 |
| DG5, BA | y = 5.618 + 1.2321 (DG5) - 0.1550 (BA) | .31 | 5.8 |
| DG5, BA, A | y = 4.309 + 1.1573 (DG5) - 0.1606 (BA) + 0.1809 (A) | .33 | 5.7 |
| | 10-YEAR DIAMETER GROWTH | | |
| BA | y = 27.422 - 0.4144 (BA) | .24 | 13.4 |
| BA, DG5 | y = 19.922 - 0.4473 (BA) + 1.8978 (DG5) | .33 | 12.6 |
| BA, DG5, HG5 | y = 18.196 - 0.4375 (BA) + 1.4105 (DG5) + 0.2048 (HG5) | .35 | 12.5 |
| | 15-YEAR DIAMETER GROWTH | | |
| BA | y = 47.832 - 0.8750 (BA) | .39 | 19.5 |
| BA, HG5 | y = 34.259 - 0.7971 (BA) + 0.7276 (HG5) | .46 | 18.4 |
| BA, HG5, AGE | y = 28.161 - 0.9096 (BA) + 0.7347 (HG5) + 0.1040 (AGE) | .49 | 18.0 |
| BA, HG5, AGE, LCR | y = 1.957 - 0.8071 (BA) + 0.7167 (HG5) + 0.1308 (AGE) + 0.3111 (LCR) | .52 | 17.6 |
| | 20-YEAR DIAMETER GROWTH | | |
| BA | y = 66.864 - 1.1536 (BA) | .48 | 22.4 |
| BA, HG5, | y = 45.542 - 1.0100 (BA) + 1.0389 (HG5) | .60 | 19.9 |
| BA, HG5, LCR | y = 10.395 - 0.8410 (BA) + 1.0058 (HG5) + 0.4523 (LCR) | .65 | 18.6 |
| BA, HG5, LCR, E | y = 156.531 - 0.8062 (BA) + 0.9065 (HG5) + 0.4432 (LCR) - 0.0763 (E) | .69 | 17.8 |
| BA, HG5, LCR, E, AGE | y = 162.973 - 0.9644 (BA) + 0.8613 (HG5) + 0.5291 (LCR) - 0.0865 (E) + 0.1341 (AGE) | .72 | 17.2 |

1/ DG5 = diameter growth 5 years before release (in millimeters); BA = postharvest overstory basal area (in square meters per hectare); A = aspect (code); HG5 = height growth 5 years before release (in centimeters); Age = total age of tree (years); LCR = live crown ratio (percent); E = elevation (in meters). Variables are arranged in the order in which they entered the regressions. Only variables that accounted for major portions of the variation in growth are given. Variables were excluded if they failed to raise $R^2$ values by at least 2 percent.

2/ All are significant at the 1-percent level.

3/ y = diameter growth in millimeters.

## Height Growth Showed Similar Response

Height growth of both fir and hemlock after release increased over the prerelease rate at a rate similar to the diameter growth response. In shelterwood and uncut units, average height growth of the firs was somewhat greater than that of hemlock during all periods except for the uncut units during the 11- to 15-year postharvest period (fig. 5). In clearcut units, this relationship was reversed; average growth of hemlock exceeded that of fir during the preharvest period and during all postharvest periods. Acceleration of growth after release began slowly during the first period, showing no change for fir in shelterwood units compared to uncut units. Height growth rates increased in subsequent periods for both fir and hemlock and reached a maximum of 4.8 times the prerelease rate for hemlock in clearcuttings during the fourth period. Actual growth during this 5-year period averaged 65 centimeters (25.5 in) for fir and 79 centimeters (31.1 in) for hemlock. This corresponds to a periodic annual growth rate of 13 centimeters (5.1 in) and 16 centimeters (6.2 in), respectively.

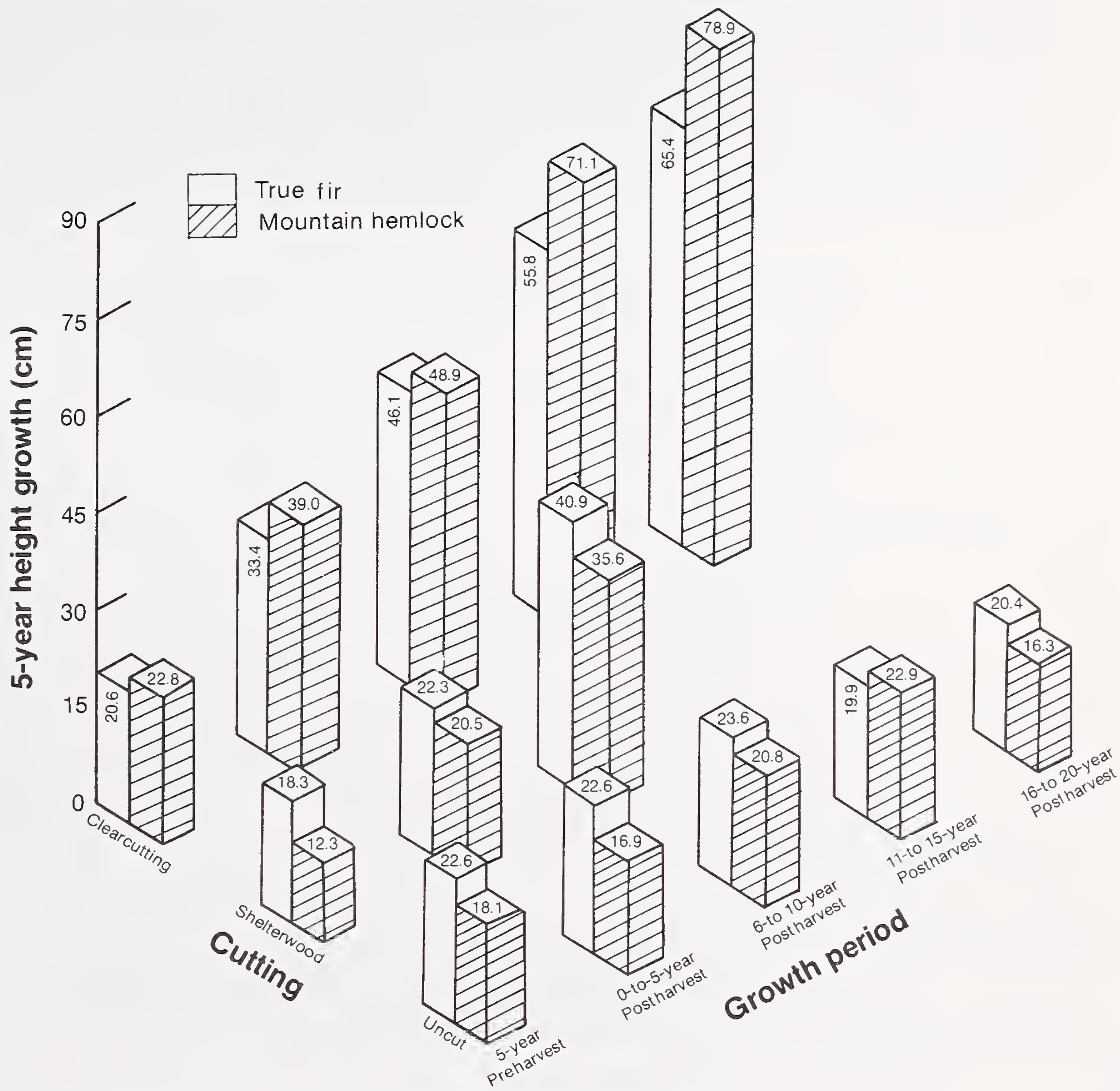


Figure 5.—Periodic height growth of true fir and mountain hemlock by cutting method and by preharvest or postharvest 5-year growth period.

The annual height growth curves for fir and hemlock in shelterwood units have common slopes but differ significantly ($P < 0.01$) in levels with fir having more rapid growth than hemlock both before and after release (fig. 6). An increase in growth for fir was not evident until the fourth year after release (when it was 1.4 times the 5-year prerelease average), while hemlock showed this same increase 2 years after release.

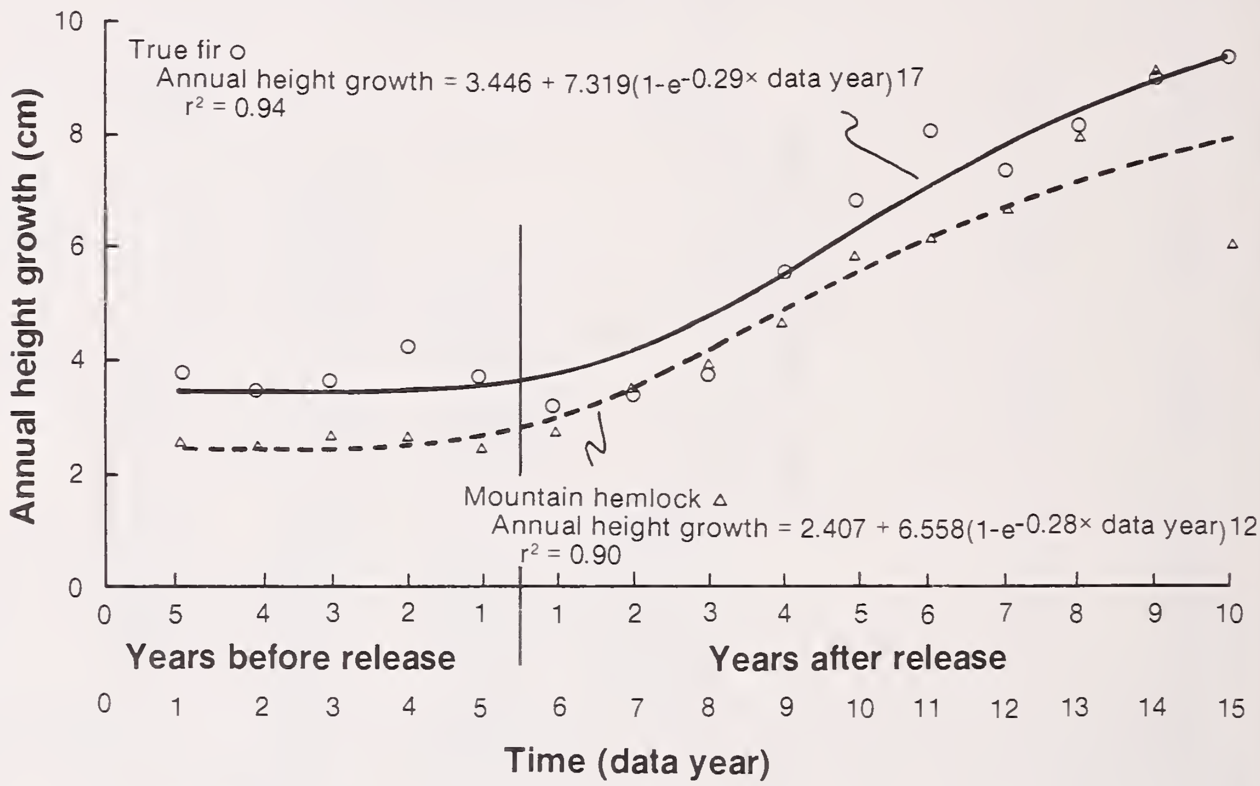


Figure 6.—Annual height growth, as a function of time, of true fir and mountain hemlock on shelterwood units. Relationship shows average growth response before and after release for all trees. Mean values for each year were used to calculate equations.

In clearcut units, fir and hemlock curves differed significantly ($P < 0.01$) in both slope and level (fig. 7). Height growth of hemlock was greater than that of fir especially 10 to 20 years after release when hemlock grew 1.3 times faster than fir. A rapid acceleration in growth of hemlock occurred the first year after release (1.5 times the prerelease rate), but increased growth of fir was delayed until the third year after release. Similar to the diameter growth curves, the height growth curves display the same sigmoid relationship with growth rates tending to level off during the third and fourth 5-year periods after release.

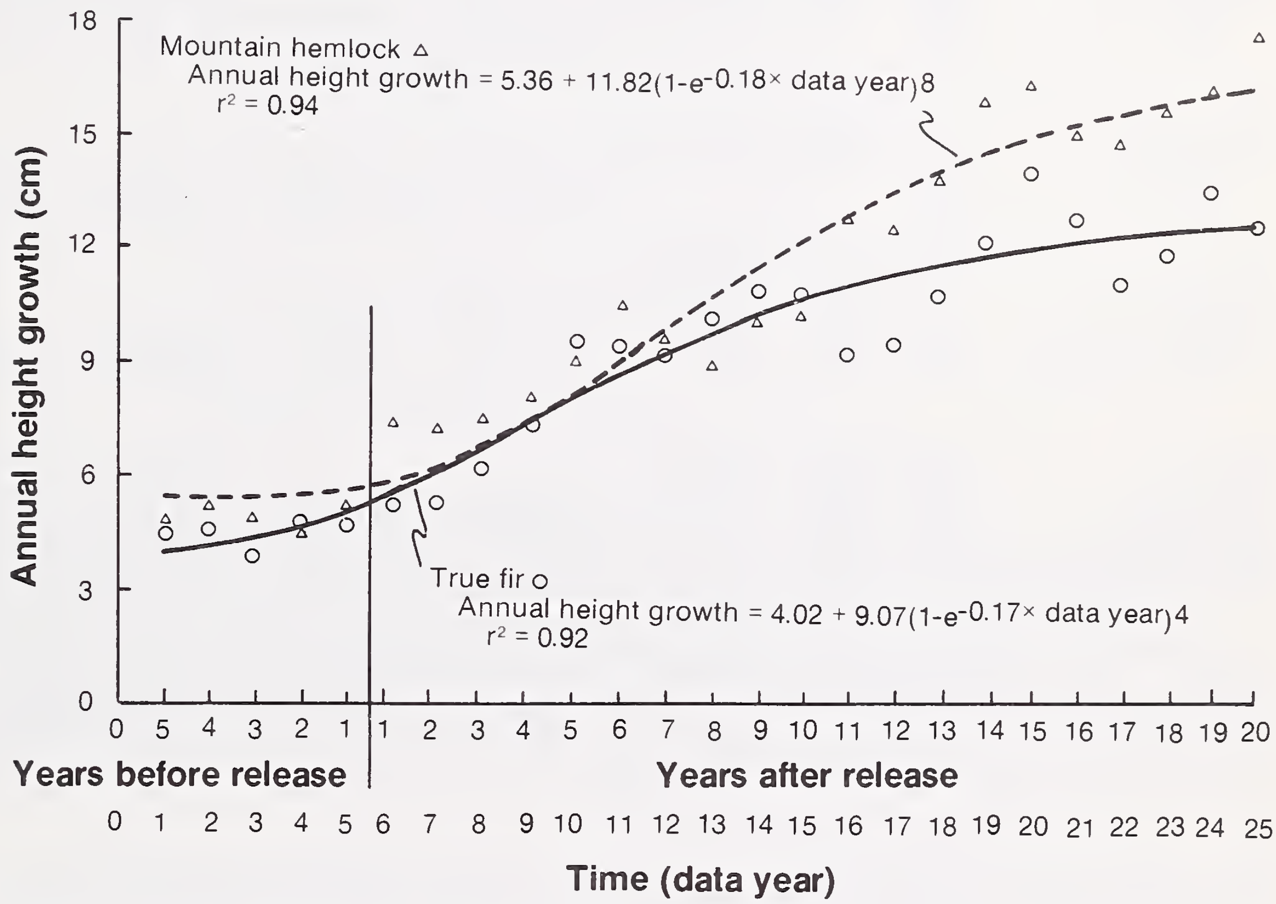


Figure 7.—Annual height growth, as a function of time, of true fir and mountain hemlock on clearcut units. Relationship shows average growth response before and after release for all trees. Mean values for each year were used to calculate equations.

**Table 4—Relationship of independent variables to 5-year, 10-year, 15-year, and 20-year height growth of suppressed understory of true fir saplings**

| Independent variables 1/ | Equation | Percent of variation explained ($R^2$) 2/ | Standard error of estimate (Sy·x) |
|---|---|---|---|
| | 5-YEAR HEIGHT GROWTH | | cm |
| HG5 | 3/ y = 7.724 + 0.9329 (HG5) | 0.30 | 19.5 |
| HG5, AGE | y = 23.644 + 0.8244 (HG5) - 0.2045 (AGE) | .39 | 18.2 |
| HG5, AGE, LCR | y = 11.383 + 0.7875 (HG5) - 0.1791 (AGE) + 0.2410 (LCR) | .44 | 17.6 |
| | 10-YEAR HEIGHT GROWTH | | |
| HG5 | y = 28.336 + 1.8201 (HG5) | .20 | 49.8 |
| HG5, LCR | y = -10.882 + 1.6277 (HG5) + 0.9195 (LCR) | .32 | 46.0 |
| HG5, LCR, AGE | y = 30.297 + 1.4133 (HG5) + 0.7869 (LCR) - 0.4564 (AGE) | .40 | 43.4 |
| | 15-YEAR HEIGHT GROWTH | | |
| BA | y = 132.800 - 2.3210 (BA) | .33 | 54.7 |
| BA, HG5 | y = 83.554 - 2.0585 (BA) + 2.3701 (HG5) | .46 | 49.2 |
| BA, HG5, LCR | y = 39.746 - 1.5506 (BA) + 2.2566 (HG5) + 0.7878 (LCR) | .52 | 46.7 |
| BA, HG5, LCR, CL | y = 30.536 - 1.2346 (BA) + 2.3905 (HG5) + 1.3966 (LCR) - 0.3848 (CL) | .57 | 44.3 |
| BA, HG5, LCR, CL, A | y = 16.801 - 1.4085 (BA) + 2.2560 (HG5) + 1.3913 (LCR) - 0.3563 (CL) + 2.1964 (A) | .60 | 43.2 |
| | 20-YEAR HEIGHT GROWTH | | |
| BA | y = 190.061 - 2.9819 (BA) | .38 | 66.9 |
| BA, A | y = 159.983 - 3.1396 (BA) + 4.9812 (A) | .47 | 62.7 |
| BA, A, HG5 | y = 113.326 - 2.9398 (BA) + 4.7823 (A) + 2.3477 (HG5) | .54 | 58.8 |
| BA, A, HG5, LCR | y = 67.562 - 2.5424 (BA) + 4.1987 (A) + 2.3637 (HG5) + 0.8425 (LCR) | .58 | 56.7 |
| BA, A, HG5, LCR, TH | y = 78.657 - 2.0345 (BA) + 4.0684 (A) + 2.9068 (HG5) + 0.9595 (LCR) - 0.2422 (TH) | .62 | 54.3 |
| BA, A, HG5, LCR, TH, DG5 | y = 74.161 - 1.8772 (BA) + 4.2991 (A) + 3.2832 (HG5) + 1.1109 (LCR) - 0.2440 (TH) - 3.4615 (DG5) | .65 | 52.9 |

1/ HG5 = height growth 5 years before release (in centimeters); AGE = total age of tree (years); LCR = live crown ratio (percent); BA = postharvest overstory basal area (in square meters per hectare); CL = crown length (in centimeters); A = aspect (code); TH = total height (in centimeters); DG5 = diameter growth 5 years before release (in millimeters). Variables are arranged in the order in which they entered the regressions. Only variables that accounted for major portions of the variation in growth are given. Variables were excluded if they failed to raise $R^2$ values by at least 2 percent.

2/ All are significant at the 1-percent level.

3/ y = height growth in centimeters.

Stepwise regression models predicting 5-, 10-, 15-, and 20-year height growth for true firs are given in table 4. As with diameter growth models, basal area, past height growth, and live crown ratio are important variables for predicting height growth. Total age in the 5-year model and aspect in the 20-year model enter as the second variable. Residual overstory basal area and past 5-year height growth were the two variables accounting for most of the variation in the hemlock height growth models (table 5). Height growth estimates based on the two-variable model (basal area and live crown ratio) are given in appendix tables 8 and 9.

**Table 5—Relationship of independent variables to 5-year, 10-year, 15-year, and 20-year height growth of suppressed understory of mountain hemlock saplings**

| Independent variables 1/ | Equation | Percent of variation explained ($R^2$) 2/ | Standard error of estimate (Sy·x) |
|---|---|---|---|
| | 5-YEAR HEIGHT GROWTH | | cm |
| HG5 | 3/ y = 9.779 + 0.9585 (HG5) | 0.24 | 19.6 |
| HG5, BA | y = 17.590 + 0.9517 (HG5) - 0.4135 (BA) | .35 | 18.1 |
| HG5, BA, TH | y = 24.159 + 0.9786 (HG5) - 0.3295 (BA) - 0.0468 (TH) | .39 | 17.7 |
| HG5,BA, TH, DG5 | y = 22.227 + 0.7639 (HG5) - 0.3375 (BA) - 0.0633 (TH) + 2.0881 (DG5) | .42 | 17.3 |
| | 10-YEAR HEIGHT GROWTH | | |
| BA | y = 88.066 - 1.2025 (BA) | .17 | 48.4 |
| BA, HG5 | y = 55.728 - 1.1904 (BA) + 1.8140 (HG5) | .32 | 43.7 |
| BA, HG5, TH | y = 71.188 - 0.9930 (BA) + 1.8771 (HG5) - 0.1101 (TH) | .36 | 42.8 |
| BA, HG5, TH, DG5 | y = 66.910 - 1.0104 (BA) + 1.4019 (HG5) - 0.1467 (TH) + 4.6233 (DG5) | .39 | 41.9 |
| | 15-YEAR HEIGHT GROWTH | | |
| BA | y = 157.090 - 2.7159 (BA) | .41 | 58.5 |
| BA, HG5 | y = 96.671 - 2.3692 (BA) + 3.2391 (HG5) | .56 | 50.9 |
| | 20-YEAR HEIGHT GROWTH | | |
| BA | y = 237.416 - 4.2349 (BA) | .49 | 80.1 |
| BA, HG5 | y = 146.134 - 3.6200 (BA) + 4.4479 (HG5) | .66 | 66.3 |
| BA, HG5, E | y = 806.311 - 3.4476 (BA) + 3.9941 (HG5) - 0.3463 (E) | .72 | 61.0 |

1/ HG5 = height growth 5 years before release (in centimeters); BA = postharvest overstory basal area (in square meters per hectare); TH = total height (in centimeters); DG5 = diameter growth 5 years before release (in centimeters); E = elevation (in meters). Variables are arranged in the order in which they entered the regressions. Only variables that accounted for major portions of the variation in growth are given. Variables were excluded if they failed to raise $R^2$ values by at least 2 percent.

2/ All are significant at the 1-percent level.

3/ y = height growth in centimeters.

Because height growth before release is an important variable in the true fir height growth models (table 4), height growth estimates for true fir based on basal area and past 5-year height growth are given in table 10 (appendix). The models give somewhat higher $R^2$ values and lower standard errors than do the models based on live crown ratio (tables 8 and 9). Past height growth is also a significant variable for predicting height growth of hemlock but estimates based on past height growth are not given for mountain hemlock because annual internodes cannot be identified in the field on standing trees.

In addition to obtaining data on the most recent growth periods of these trees (immediately before and after release), the stem analysis procedure provided an opportunity to determine the seedling height growth pattern—the number of years required for trees to reach a breast height of 137 centimeters (4.5 ft). The average number of years for both fir and hemlock to reach breast height varied from 54 to 76 years (table 1) and the overall mean was 62 years for fir and 58 years for hemlock. This corresponds to a mean height growth rate of about 2.3 centimeters (0.9 in) per year during the seedling establishment period. Although the average growth rate is relatively uniform, the growth rate of individual trees varies widely. The extremes of height growth are illustrated by the data for fir in uncut stands where 10 to 217 years were needed for trees to reach breast height or a growth rate of from 13.7 centimeters (5.4 in) to 0.63 centimeters (0.25 in) per year.

## Discussion

The results of this study show clearly that advance reproduction of both true fir and mountain hemlock respond in the same manner to release. Diameter and height growth of fir and hemlock saplings are directly proportional to tree vigor, as measured by live crown ratio or height growth before release, and inversely proportional to overstory stand density. In other words, the greatest growth occurred on full-crowned trees in clearcuttings; growth was intermediate in shelterwood units and slowest in uncut stands. Based on average growth rates, it is reasonable to expect an increase in diameter and height growth after release of from two to four times the prerelease growth rate for both fir and hemlock. Increased growth rates generally occur within 5 years after release, reach a maximum after about 10 years, and continue at this rate for at least 20 years.

Both firs and mountain hemlock responded to release with dramatic diameter growth increases regardless of age. The greatest growth response was found on a 150-year-old grand fir that grew 2.6 centimeters (1 in) in diameter during the 133 years before release and 9.2 centimeters (3.6 in) in 17 years after release— a postrelease growth rate about 27 times the prerelease rate. A 186-year-old mountain hemlock increased its diameter growth rate about 19 times from 7.2 centimeters (2.8 in) during the 168-year prerelease period to 14.7 centimeters (5.8 in) during the 18-year postrelease period.

One factor to consider in evaluating the comparative advantage of advance reproduction versus planted seedlings or natural regeneration is the height growth rates of each type of regeneration (Seidel 1980a). The height growth estimates given in appendix tables 8, 9, and 10 provide some of the information needed to make such an evaluation for mixed conifer and mountain hemlock communities on the east slope of the Oregon Cascade Range. The diameter and height growth models developed in this study were not validated with an independent data set because the additional data collected in 1984 were used to improve the original models. Those using these models should, therefore, test them by comparing actual growth observed on released trees with the estimated growth to determine if the models give reasonable estimates.

Another important factor to consider when evaluating the suitability of suppressed grand fir or white fir for future crop trees is the potential of future volume losses caused by the Indian paint fungus (*Echinodontium tinctorium* E & E). Filip and others (1983) have prepared guidelines for reducing heartrot losses from this disease. They recommend selecting vigorous crop trees based on a live crown ratio of at least 50 percent and current annual height growth of at least 20 centimeters (8 in). In my study, the maximum average annual height growth of fir in clearcuttings was about 13 centimeters (5 in) 20 years after release, although 30 percent of the firs sampled in clearcuttings grew 20 centimeters (8 in) or more in height during their last growing season.

It is now apparent from studies of the response of suppressed advance reproduction to release in various plant communities in the west that shade tolerant species, such as firs, spruces, and hemlocks, have the capacity to greatly increase diameter and height growth after overstory removal or after thinning. It is also evident that the most vigorous trees grow the fastest and that the two individual tree variables most strongly correlated with tree vigor are live crown ratio and past 5-year height growth (Ferguson and Adams 1979, McCaughey and Schmidt 1982, Seidel 1980b). Thus, advance reproduction can easily be evaluated in the field to determine its management potential. Selecting only vigorous reproduction for management not only results in the greatest growth response after overstory removal but also in the most protection against heartrots because rapidly growing trees are better able to compartmentalize any decay columns resulting from wounding of the tree (Shigo and Marx 1977).

## Conversion Factors

1 meter = 3.2808 feet
1 centimeter = 0.3937 inches
1 millimeter = 0.03937 inches
1 square meter per hectare = 4.356 square feet per acre

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## Appendix

**Table 6—10-year diameter growth estimates of suppressed understory of true fir and mountain hemlock as a function of live crown ratio and residual overstory basal area[1/]**

| | Live crown ratio | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Residual basal area | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Square meters per hectare | | | | | Millimeters | | | | | |
| | | | | | TRUE FIR | | | | | |
| 0 | 19 | 22 | 25 | 28 | 31 | 34 | 37 | 40 | 43 | 46 |
| 9.2 | 14 | 17 | 21 | 24 | 27 | 30 | 33 | 36 | 39 | 42 |
| 18.4 | 11 | 14 | 17 | 20 | 23 | 26 | 29 | 32 | 35 | 38 |
| 27.5 | 7 | 10 | 13 | 16 | 19 | 22 | 25 | 28 | 31 | 34 |
| 36.7 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 |
| 45.9 | | 1 | 4 | 7 | 10 | 13 | 16 | 19 | 22 | 25 |
| $y = 15.431 + 0.3095 X_1 - 0.4493 X_2$ | | | | | | $R^2 = 0.39$; $n = 245$; $Sy{\cdot}x = 14.5$ mm | | | | |
| | | | | | MOUNTAIN HEMLOCK | | | | | |
| 0 | 12 | 14 | 16 | 19 | 21 | 23 | 26 | 28 | 30 | 33 |
| 9.2 | 9 | 11 | 13 | 16 | 18 | 20 | 23 | 25 | 27 | 30 |
| 18.4 | 5 | 8 | 10 | 12 | 15 | 17 | 20 | 22 | 24 | 27 |
| 27.5 | 2 | 5 | 7 | 9 | 12 | 14 | 17 | 19 | 21 | 24 |
| 36.7 | | 2 | 4 | 6 | 9 | 11 | 14 | 16 | 18 | 21 |
| 45.9 | | | 1 | 3 | 5 | 7 | 10 | 12 | 14 | 17 |
| $y = 9.313 + 0.2344 X_1 - 0.3378 X_2$ | | | | | | $R^2 = 0.29$; $n = 155$; $Sy{\cdot}x = 13.0$ mm | | | | |

[1/] Limits of basic plot data enclosed within solid line.
$y$ = 10-year diameter growth, in millimeters;
$X_1$ = live crown ratio; and
$X_2$ = residual basal area, in square meters per hectare.

**Table 7—20-year diameter growth estimates of suppressed understory of true fir and mountain hemlock as a function of live crown ratio and residual overstory basal area[1/]**

| | Live crown ratio | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Residual basal area | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Square meters per hectare | Millimeters | | | | | | | | | |
| | TRUE FIR | | | | | | | | | |
| 0 | 47 | 52 | 57 | 62 | 67 | 72 | 77 | 82 | 86 | 91 |
| 9.2 | 36 | 41 | 46 | 51 | 56 | 61 | 66 | 71 | 75 | 80 |
| 18.4 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 64 | 69 |
| 27.5 | 14 | 19 | 24 | 29 | 34 | 39 | 44 | 49 | 53 | 58 |
| 36.7 | 3 | 8 | 13 | 18 | 23 | 28 | 33 | 38 | 42 | 47 |
| 45.9 | | | 2 | 7 | 12 | 17 | 22 | 27 | 31 | 36 |
| $y = 42.367 + 0.4892\ X_1 - 1.1942\ X_2$ | | | | | | $R^2 = 0.57$; n = 65; $S_{y \cdot x}$ = 23.5 mm | | | | |
| | MOUNTAIN HEMLOCK | | | | | | | | | |
| 0 | 33 | 38 | 43 | 48 | 53 | 58 | 62 | 67 | 72 | 77 |
| 9.2 | 25 | 29 | 34 | 39 | 44 | 49 | 54 | 58 | 63 | 68 |
| 18.4 | 15 | 20 | 25 | 30 | 35 | 40 | 44 | 49 | 54 | 59 |
| 27.5 | 6 | 11 | 16 | 21 | 26 | 31 | 35 | 40 | 45 | 50 |
| 36.7 | | 2 | 7 | 12 | 17 | 22 | 26 | 31 | 36 | 41 |
| 45.9 | | | | 4 | 9 | 14 | 18 | 23 | 28 | 33 |
| $y = 28.620 + 0.4828\ X_1 - 0.9681\ X_2$ | | | | | | $R^2 = 0.54$; n = 63; $S_{y \cdot x}$ = 21.2 mm | | | | |

1/ Limits of basic plot data enclosed within solid line.
$y$ = 20-year diameter growth, in millimeters;
$X_1$ = live crown ratio; and
$X_2$ = residual basal area, in square meters per hectare.

## Table 8—10-year height growth estimates of suppressed understory of true fir and mountain hemlock as a function of live crown ratio and residual overstory basal area[1/]

| Residual basal area | Live crown ratio 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Square meters per hectare | Centimeters | | | | | | | | | |
| **TRUE FIR** | | | | | | | | | | |
| 0 | 55 | 62 | 70 | 78 | 86 | 94 | 101 | 109 | 117 | 125 |
| 9.2 | 46 | 54 | 62 | 69 | 77 | 85 | 93 | 101 | 108 | 116 |
| 18.4 | 38 | 45 | 53 | 61 | 69 | 77 | 84 | 92 | 100 | 108 |
| 27.5 | 30 | 37 | 45 | 53 | 61 | 69 | 76 | 84 | 92 | 100 |
| 36.7 | 21 | 28 | 36 | 44 | 52 | 60 | 67 | 75 | 83 | 91 |
| 45.9 | 13 | 20 | 28 | 36 | 44 | 52 | 59 | 67 | 75 | 83 |
| $y = 46.812 + 0.7796 X_1 - 0.9235 X_2$ | | | | | | $R^2 = 0.22$; n = 245; $S_{y \cdot x}$ = 49.2 cm | | | | |
| **MOUNTAIN HEMLOCK** | | | | | | | | | | |
| 0 | 28 | 37 | 46 | 55 | 64 | 73 | 82 | 91 | 100 | 109 |
| 9.2 | 19 | 28 | 37 | 46 | 55 | 64 | 73 | 82 | 91 | 101 |
| 18.4 | 11 | 20 | 29 | 38 | 47 | 56 | 65 | 74 | 83 | 92 |
| 27.5 | 3 | 12 | 21 | 30 | 39 | 48 | 57 | 66 | 75 | 84 |
| 36.7 | | 4 | 13 | 22 | 31 | 40 | 49 | 58 | 67 | 76 |
| 45.9 | | | 4 | 13 | 22 | 31 | 40 | 49 | 58 | 67 |
| $y = 18.704 + 0.8981 X_1 - 0.9089 X_2$ | | | | | | $R^2 = 0.23$; n = 155; $S_{y \cdot x}$ = 46.6 cm | | | | |

1/ Limits of basic plot data enclosed within solid line.
$y$ = 10-year height growth, in centimeters;
$X_1$ = live crown ratio; and
$X_2$ = residual basal area, in square meters per hectare.

**Table 9—20-year height growth estimates of suppressed understory of true fir and mountain hemlock as a function of live crown ratio and residual overstory basal area[1/]**

| Residual basal area | Live crown ratio 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Square meters per hectare | Centimeters | | | | | | | | | |
| | TRUE FIR | | | | | | | | | |
| 0 | 141 | 152 | 162 | 172 | 182 | 192 | 202 | 212 | 222 | 232 |
| 9.2 | 118 | 128 | 138 | 149 | 159 | 169 | 179 | 189 | 199 | 209 |
| 18.4 | 94 | 105 | 115 | 125 | 135 | 145 | 155 | 165 | 175 | 185 |
| 27.5 | 71 | 82 | 92 | 102 | 112 | 122 | 132 | 142 | 152 | 162 |
| 36.7 | 48 | 59 | 69 | 79 | 89 | 99 | 109 | 119 | 129 | 139 |
| 45.9 | 25 | 36 | 46 | 56 | 66 | 76 | 86 | 96 | 106 | 116 |

$y = 131.395 + 1.0095\ X_1 - 2.5295\ X_2$ $\qquad R^2 = 0.44;\ n = 65;\ Sy{\cdot}x = 64.1$ cm

| Residual basal area | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| | MOUNTAIN HEMLOCK | | | | | | | | | |
| 0 | 190 | 197 | 203 | 210 | 217 | 224 | 231 | 238 | 245 | 252 |
| 9.2 | 153 | 160 | 167 | 174 | 181 | 188 | 195 | 201 | 208 | 215 |
| 18.4 | 117 | 124 | 130 | 137 | 144 | 151 | 158 | 165 | 172 | 179 |
| 27.5 | 81 | 88 | 94 | 101 | 108 | 115 | 122 | 129 | 136 | 143 |
| 36.7 | 44 | 51 | 57 | 64 | 71 | 78 | 85 | 92 | 99 | 106 |
| 45.9 | 7 | 15 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 |

$y = 182.815 + 0.6893\ X_1 - 3.9700\ X_2$ $\qquad R^2 = 0.50;\ n = 63;\ Sy{\cdot}x = 80.0$ cm

1/ Limits of basic plot data enclosed within solid line.
$y$ = 20-year height growth, in centimeters;
$X_1$ = live crown ratio; and
$X_2$ = residual basal area, in square meters per hectare.

**Table 10—10 and 20-year height growth estimates of suppressed understory of true fir as a function of past 5-year height growth and residual overstory basal area[1/]**

| Residual basal area | Past 5-year height growth (in centimeters) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 |
| Square meters per hectare | | | | Centimeters | | | | |
| | | | | 10-YEAR HEIGHT GROWTH | | | | |
| 0 | 61 | 77 | 94 | 110 | 127 | 143 | 160 | 176 |
| 9.2 | 50 | 67 | 83 | 100 | 116 | 133 | 149 | 166 |
| 18.4 | 39 | 55 | 72 | 88 | 105 | 121 | 138 | 154 |
| 27.5 | 29 | 45 | 62 | 78 | 95 | 111 | 128 | 144 |
| 36.7 | 18 | 34 | 51 | 67 | 84 | 100 | 117 | 133 |
| 45.9 | 7 | 23 | 40 | 56 | 73 | 89 | 106 | 122 |
| 55.1 | | 12 | 29 | 45 | 62 | 78 | 95 | 111 |
| 64.3 | | 2 | 19 | 35 | 52 | 68 | 85 | 101 |
| $y = 52.546 + 1.652\,X_1 - 1.173\,X_2$ | | | | | $R^2 = 0.31$; n = 245; Sy·x = 46.4 cm | | | |
| | | | | 20-YEAR HEIGHT GROWTH | | | | |
| 0 | 152 | 177 | 201 | 206 | 250 | 275 | 299 | 324 |
| 9.2 | 127 | 151 | 176 | 200 | 225 | 249 | 274 | 298 |
| 18.4 | 101 | 126 | 150 | 175 | 199 | 224 | 248 | 273 |
| 27.5 | 76 | 101 | 125 | 150 | 174 | 199 | 223 | 248 |
| 36.7 | 50 | 75 | 99 | 124 | 148 | 173 | 197 | 222 |
| 45.9 | 24 | 49 | 73 | 98 | 122 | 147 | 171 | 196 |
| 55.1 | | 24 | 48 | 73 | 97 | 122 | 146 | 171 |
| 64.3 | | | 22 | 47 | 71 | 96 | 120 | 145 |
| $y = 140.072 + 2.4523\,X_1 - 2.7798\,X_2$ | | | | | $R^2 = 0.46$; n = 65; Sy·x = 63.0 cm | | | |

1/ Limits of basic plot data within solid line.
$\bar{y}$ = height growth, in centimeters;
$X_1$ = past 5-year height growth, in centimeters; and
$X_2$ = residual basal area, in square meters per hectare.

*GPO 691 - 230 (1985)

**Seidel, K. W.** Growth response of suppressed true fir and mountain hemlock after release. Res. Pap. PNW-344. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 22 p.

The diameter and height growth of advance reproduction of suppressed true fir (*Abies* spp.) and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) was measured in south-central Oregon after release by overstory removal in clearcuttings, shelterwood units, and uncut stands. Postrelease growth was greatest in clearcuttings, intermediate in shelterwood cuttings, and slowest in uncut stands. Multiple regression analyses were used to predict growth response as a function of tree and stand variables. Overstory basal area, live crown ratio, and past 5-year height growth accounted for the most variation in diameter and height growth after release. Vigorous advance reproduction having live crown ratios greater than 50 percent are the best candidates for crop trees.

Keywords: Growth response, release, suppression (tree), advance growth, true fir, mountain hemlock.

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